TIRE NOISE ASSESSMENT OF ASPHALT RUBBER CRUMB PAVEMENT

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Abstract

Due to ever-increasing traffic volumes, various mitigating techniques are commonly employed to reduce tire noise. One such method is the use of Asphalt Rubber Crumb (ARC) pavement as a surface coat for conventional asphalt. Crushed rubber tires are heated to a gel-state and mixed in with the conventional asphalt, resulting in a more porous and less stiff surface material. Measurements were conducted at a pilot paving location where sections of old conventional pavement were repaved with new ARC and new conventional pavement. These locations enabled direct comparison between the two paving materials. Measurements conducted included: long term environmental noise monitoring, short term specific vehicle observed sound levels, specific controlled vehicle drive-by tests and subjective observations. The paper outlines the measurement methods and the results obtained.

1. INTRODUCTION

With the ever increasing traffic volumes and prevalent desire to minimize residential noise levels, various noise mitigating methods are commonly employed. The most common source of traffic noise (away from intersections) is the noise generated by the interaction of vehicle tires and the road surface. The noise levels generated are dependent on many factors such as tire composition, road condition, vehicle speed, number of tires, and road composition. It is the latter, road composition, that is the subject of this paper.

The use of Asphalt Rubber Crumb (ARC) pavement is widespread in the southern United States, and has a proven track record of performance [1]. Use of ARC in Canada, however, has been limited mainly to pilot projects covering relatively short sections of road. The purpose of this paper is to present and discuss measured noise level results obtained during a pilot ARC paving project conducted in and around Edmonton, Alberta in 2003.

2. PAVEMENT DESCRIPTION

Typical conventional asphalt pavement is comprised of aggregate (small rock) and a binder of 5% to 6% conventional asphalt cement by total weight [2]. The ARC mix used for the study contained approximately 7.5% to 8.5% asphalt rubber binder by total weight. The asphalt rubber binder itself contained approximately 19% rubber crumb by weight, thus about 1.4% to 1.6% of the total ARC pavement contained the rubber crumb. The rubber crumb typically comes from recycled vehicle tires. For this study the primary source was large truck tires.

In production, the asphalt mix is heated to approximately 190°C and the rubber crumb is added, then the temperature is increased to 205°C. This temperature is not actually hot enough to melt the rubber, rather the rubber becomes gel-like and surrounds and bonds with the asphalt cement. Once the production process is complete, the ARC pavement is transported and applied using the same methods as conventional asphalt. The final product (as a road surface) looks more coarse and porous than conventional asphalt as shown in Figure 1.

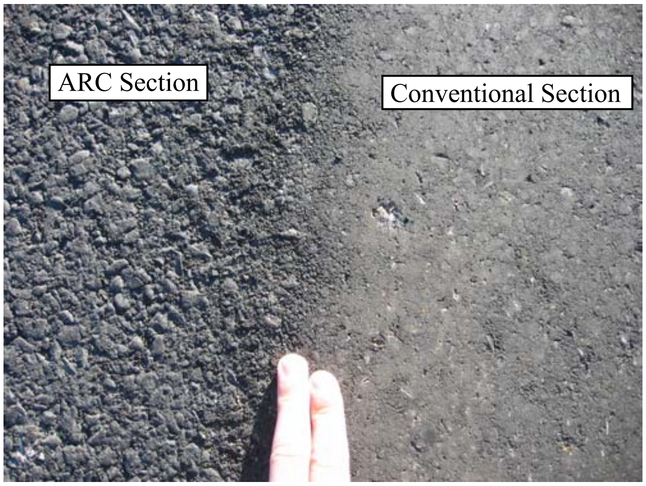

Figure 1. ARC and Conventional Asphalt

The physical mechanics of how the ARC reduces tire noise are not presented in this paper. In general, however, the material is more porous and sound absorbing than conventional asphalt. In addition, although the ARC surface feels rougher than conventional asphalt, there is a greater flexibility (because of the rubber content) which results in more "give" under the pressure of the tire.

3. MEASUREMENT DESCRIPTION

Various road sections in and around the Edmonton area were paved with ARC as part of the 2003 pilot project. Most sections used ARC over existing conventional asphalt that was old and cracking. As such, the direct comparison of *before* v.s. *after* would not necessarily point to the benefits of ARC v.s. conventional pavement. At one highway location, however, a 7 km stretch of old conventional pavement was re-surfaced with ARC pavement, and an adjacent 14 km stretch was re-surfaced with new conventional pavement. As such, a direct comparison could be made with *before* and *after* conditions for both ARC and conventional pavement.

One common method for measuring road noise is outlined in ISO 11819-1 [3]. This method requires the use of a radar gun to determine each vehicles specific speed, as well as measuring a minimum number of specific vehicle types. The data collected is then used to calculate the Statistical Pass-By Index (SPBI). It is this single value which can be used to compare to different measurement locations. Several factors rendered this method undesirable for the purposes of this study. For example, the overall number of various vehicle types within a 1-day period, for example, would not have been sufficient to meet the requirements of the standard. In addition, the primary information desired was a comparison of *before* v.s. *after* which did not warrant as detailed traffic and vehicle speed information as that gathered via the standard. Finally, the standard does not provide information on the relative frequency content of the measured noise. It was desired to have a 1/3 octave spectral comparison of *before* v.s. *after*. It should be noted that although the exact measurement methods outlined in ISO 11819-1 were not used, much of the document was used as a reference for other measurement parameters such as microphone locations, environmental concerns, etc.

Several different types of measurements were conducted at the study location to quantify the amount of noise reduction. The highway section in question consisted of a single lane in each direction and a posted speed limit of 100 km/hr. Each of the measurement methods are described in sections 3.1 – 3.4.

3.1. LONG TERM NOISE MONITORING

A 26-hour environmental noise monitoring was conducted at both the ARC and conventional pavement locations both *before* and *after* the application of the new surface. The noise monitoring was conducted using a 30-second L_{eq} time period in both broadband (linear and A-weighted) and 1/3 octave band spectral analysis. In each case, the noise monitor was located approximately 20m from the centerline of the road. The key was to maintain the same location for both the *before* and *after* measurements to minimize the effects of distance attenuation, ground absorption, air absorption, and surface reflections. The 26-hour time was used so that a 2-hour observation period could be used at the same time on two consecutive days to document traffic conditions. This was important to determine the consistency in traffic from the *before* period to the *after* period (more than 1-month time lapsed while paving commenced).

3.2. SHORT TERM MAXIMUM SOUND LEVELS

While on site for the 2-hour observation periods, the short term maximum sound levels obtained with specific vehicle pass-by's were noted. These maximum sound levels were collected and analyzed statistically to further determine the consistency in traffic conditions for each observation period, as well as give another measure of the amount of noise reduction. The different vehicle classifications were; light autos (car, minivan, mini-pickup), busses, large trucks with single rear axles, and large trucks with multiple rear axles. Vehicles which did not fit into these categories or were considered non-typical (i.e. modified muffler, unusually loud engine, etc.) were not recorded.

3.3. CONTROLLED VEHICLE TESTING

The final measurement involved the use of a specific vehicle for controlled drive-by testing. A 2002 Dodge Grand Caravan (a very common vehicle type) was driven by the sound level meter (located exactly 10m from the centerline of the road at a height of 1m) at a constant speed (100 km/hr), in each road direction. The tests were conducted with the engine on (operating with cruise control) and off. This was accomplished by accelerating the vehicle up to slightly higher than 100 km/hr, then shifting into neutral and turning the engine off approximately 200m before passing by the sound level meter.

The sound level meter was set to measure with 1-second L_{eq} sound levels in both broadband (linear and A-weighted) and 1/3 octave band spectra. The measurements were started once the vehicle was within approximately 200 – 300m of the sound level meter and stopped once it had passed to approximately 200 – 300m away from the sound level meter. As with the other measurements, the controlled drive-by testing was conducted at both the ARC and conventional asphalt locations both *before* and *after* repaving.

3.4 SHORT TERM SUBJECTIVE OBSERVATIONS

While on site for the 2-hour observation periods, subjective observations were noted. These included notes on the relative frequency content of the vehicle noise, specific noise sources emanating from the vehicles, qualitative assessment of broadband sound levels, and estimation of the maximum audible distance of the vehicle. As well as the subjective notes maintained, audio recordings were obtained for specific vehicle pass-by's. This information was used to confirm site observations once back in the office.

4.1. RESULTS: LONG TERM NOISE MONITORING

The results of the long term noise monitoring are presented in Table 1. It can be seen that there was a reduction in sound levels with the application of the ARC and conventional asphalts. The amount of reduction with the ARC, however, was greater. It should be noted that two key external factors affected the measured sound levels. First, the sound levels obtained at the conventional asphalt section during the *before* time-period were notably higher than typical due to the presence of many dump-trucks hauling material used for paving the ARC section. It is estimated that the day-time sound levels would have been approximately 2-3 dBA lower than those measured resulting in less of a reduction from *before* to *after*. Second, the sound levels obtained at the ARC section during the *after* time-period were slightly higher than they otherwise would have been due to the presence of farm machinery (swathing machine) operating in the adjacent field during the daytime. As a result, the daytime sound levels would have been approximately 1-2 dBA lower, resulting in a larger reduction in the sound levels from *before* to *after*. Both of these factors would have resulted in L_{eq}Day and L_{eq}24 sound reductions of approximately 6 dBA for the ARC section and 2 dBA for the conventional section.

It should also be pointed out that the number of vehicles on the study highway during the night-time is typically less than 10 vehicles per hour. As a result, even small changes in vehicle counts for the night-time period will result in large changes to the L_{eq}Night. Due to this, the L_{eq}Night is not particularly useful for comparison at this location. It can be seen that there was more of a reduction at the conventional location compared to the ARC location during the night-time.

Table 1. Long Term Noise Monitoring Results

	Leq24 (dBA)	**LeqDay* (dBA)**	**LeqNight (dBA)**
Before (ARC)	57.8	59.2	52.9
After (ARC)	53.1**	54.9**	44.8
Difference (ARC)	**-4.7**	**-4.4**	**-8.1**
Before (Conventional)	58.7***	60.0***	54.8
After (Conventional)	54.5	56.3	46.0
Difference (Conventional)	**-4.2**	**-3.7**	**-8.8**

* Day-time hours are 07:00 – 22:00; night-time hours are 22:00 – 07:00

** Farm machinery operating in nearby field during day-time (results estimated to be 1-2 dBA higher than normal)

*** Abnormally high volume of dump-trucks during day-time (results estimated to be 2-3 dBA higher than normal)

The long term noise monitoring 1/3 octave band spectral results are shown in Figs. 2 and 3. Both pavement types resulted in only moderate sound level reductions in the low to mid frequencies (up to approximately 800Hz). Beyond 800Hz, however, the ARC resulted in much greater sound level reductions than the conventional pavement. These frequencies are important as they cover the range to which humans are the most sensitive and cover a large portion of the range of human speech frequencies.

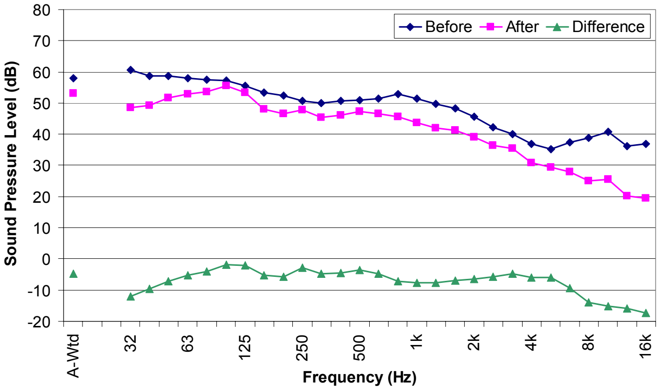

Figure 2. ARC Section 1/3 Octave 26-hour Results

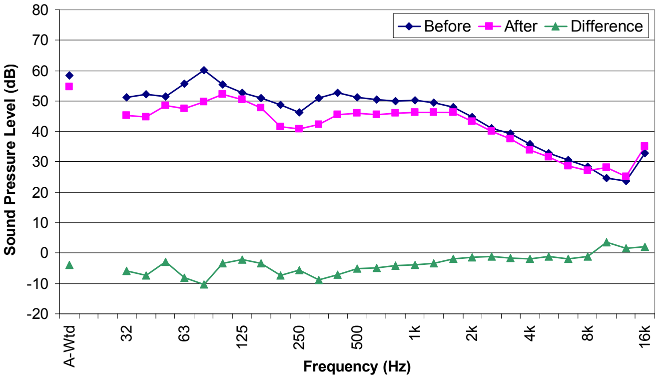

Figure 3. Conventional Section 1/3 Octave 26-hour Results

4.2. RESULTS: SHORT TERM MAX SOUND LEVELS

As mentioned previously, 2-hour observation periods at the start and end of the long term noise monitoring were used to obtain maximum sound levels for specific vehicle types. Tables 2 and 3 (end of paper) contain the averaged sound levels as well as their respective standard deviations for the various vehicle types during each of the 2-hour periods. The results displayed in Tables 2 and 3 match very well with those of the long term results once the various noise anomalies (farm machinery and dump-trucks as mentioned previously) are taken into account. It can be seen that for the light autos, the sound level reductions are much greater with the ARC section than the conventional pavement section. There is an increased amount of reduction with larger vehicles as well, but the difference between the ARC and conventional is not as great. This gives evidence that less of the total noise emanating from the larger vehicles is associated with tire noise than compared to the light autos (which is as expected).

4.3. RESULTS: CONTROLLED VEHICLE TESTING

The final measurements were with the use of a controlled vehicle pass-by. The parameters for the test are described in section 3.3. Figure 4 shows the 1/3 octave band sound levels for the *before* measurements and both *after* measurements (ARC and conventional pavement). The results shown are the average of the cumulative measurement L_{eq}'s for the 4 individual pass-by's for each location.

At frequencies below 500 Hz, there is little difference between the three curves. Between 630 Hz and 1 kHz, there is a significant reduction in the sound levels (approximately 10 dB) for both the *after* ARC and conventional sections compared to the *before* measurements. Beyond 1.25 kHz, however, the conventional *after* results are essentially identical to the *before* results while the ARC results are approximately 5 dB lower. Again, these results match well with those of the long term noise monitoring.

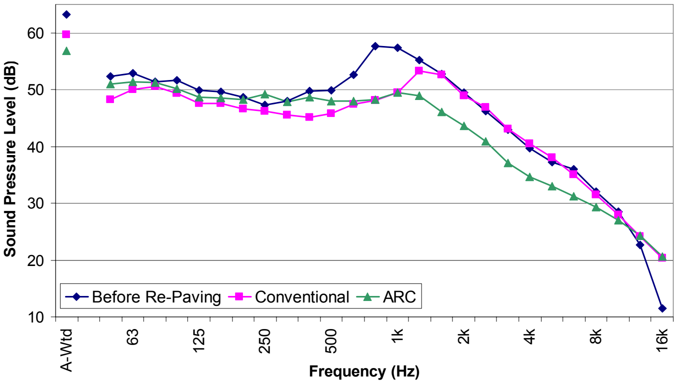

Figure 4. Controlled Vehicle Test 1/3 Octave Band Results

In addition to the 1/3 octave band frequency results, the controlled vehicle tests also illustrate the increase in the slope for the rise and fall of the sound levels resulting from the passing vehicle. Figures 5 and 6 show the sound levels vs. time for the ARC and conventional sections, respectively, during a "typical" vehicle passage. Each of the bars represents 1 second of time. It can be seen that the rise and fall times for the ARC section are much steeper than those of the conventional section. Thus, in conjunction with reduced maximum sound levels, the ARC pavement also reduces the length of time during which the higher vehicle pass-by sound levels occur. The net effect is that residents in proximity to the roadway would experience both lowered maximum sound levels and shorter exposure times (both of which affect the L_{eq} sound levels).

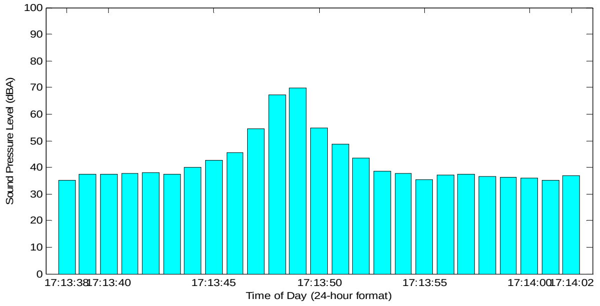

Figure 5. Time Domain Pass-by Sound Levels at ARC Section

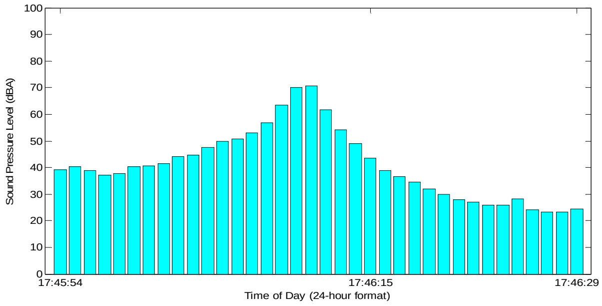

Figure 6. Time Domain Pass-by Sound Levels at Conventional Section

4.4. RESULTS:
SUBJECTIVE OBSERVATIONS

At all times during the various measurement periods, subjective observations were noted. In general, it was noted that the use of ARC resulted in lower overall noise levels, as well as a substantially notable reduction in the mid to high frequencies. Essentially, it sounded as if the tire noise was somewhat "muffled" compared to both the old and new conventional pavement. The new conventional pavement was noted to have a slightly noticeable reduction in noise levels, but the frequency content of the noise did not change.

One of the most important observations was related to the distance at which a vehicle could be heard. While observing the old conventional asphalt, an individual vehicle (in absence of other noise sources) could be heard for more than 1 km and up to 2 km in some cases. This remained essentially the same after the application of the new conventional pavement. With the application of the ARC, however, vehicles could generally not be heard beyond 300 – 400m. At several times during the *after* measurements for the ARC section, vehicles would essentially "sneak up" on the observer whereas during the *before* measurements, the observer knew well in advance when a vehicle was coming.

5.5. FUTURE WORK

Although the pilot study revealed much information regarding the noise attenuation capabilities of ARC pavement, there are still many important unknowns which should be addressed. Of prime importance for most locations within Canada is the effect of winter. The noise attenuation capabilities of ARC are unknown at freezing temperatures. In addition, the effects of one or several freeze/thaw cycles should be investigated. Road surface conditions such as partial snow or dirt/mud coverage and varying stages of road repair could also have an impact on the noise levels. Also, variable mixtures of ARC could be investigated to find an optimal mixture for noise reduction. Finally, other vehicle related aspects such as different vehicle speeds could be investigated to determine the relative reduction levels for highway conditions compared to urban roads with slower speeds.

6.0. CONCLUSION

The use of asphalt rubber crumb pavement as a road surface material has been quantitatively and subjectively noted to reduce tire noise levels compared to conventional asphalt pavement. The various measurement techniques used to quantify the level of reduction all achieved similar results and the measured data corroborated well with subjective observations. Further work is also required to determine the longevity of the noise reduction benefits.

REFERENCES

1. Rubber Pavements Association, 1801 South Jentlilly Lane, Suite A-2, Tempe, AZ 85281 USA, Web: www.rubberpavements.org
2. Alberta Rubber Asphalt Project Report, Prepared for the Consulting Engineers of Alberta by EBA Engineering Consultants Ltd. of Edmonton.
3. ISO 11819-1:1997(E)
   Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 1: Statistical Pass-By Method

Table 2. Maximum Observed Sound Levels at ARC Location

	Day 1 (*before*) Max Avg. (dBA)	Day 1 (*before*) Std. Dev (dBA)	Day 2 (*before*) Max Avg. (dBA)	Day 2 (*before*) Std. Dev (dBA)	Day 1 (*after*) Max Avg. (dBA)	Day 1 (*after*) Std. Dev (dBA)	Day 2 (*after*) Max Avg. (dBA)	Day 2 (*after*) Std. Dev (dBA)	Average Difference (*After - Before*) (dBA)
Light Autos (E)	72.2	2.2	71.6	1.9	64.7	1.3	63.2	1.7	-7.9
Light Autos (W)	70.3	2.1	70.8	1.6	64.1	1.4	64.1	1.9	-6.5
Large Truck, Single-Axle (E)	N/A	N/A	N/A	N/A	71.0	0.0	N/A	N/A	N/A
Large Truck, Single-Axle (W)	73.0	1.7	N/A	N/A	70.5	4.9	68.7	3.2	-3.4
Large Truck, Multi-Axle (E)	76.0	0.0	80.9	1.2	76.0	N.A	N/A	N/A	-2.4
Large Truck, Multi-Axle (W)	N/A	N/A	77.9	2.9	76.0	N/A	74.0	1.0	-2.9

Table 3. Maximum Observed Sound Levels at Conventional Location

	Day 1 (*before*) Max Avg. (dBA)	Day 1 (*before*) Std. Dev (dBA)	Day 2 (*before*) Max Avg. (dBA)	Day 2 (*before*) Std. Dev (dBA)	Day 1 (*after*) Max Avg. (dBA)	Day 1 (*after*) Std. Dev (dBA)	Day 2 (*after*) Max Avg. (dBA)	Day 2 (*after*) Std. Dev (dBA)	Average Difference (*After - Before*) (dBA)
Light Autos (N)	71.6	2.1	71.3	1.8	69.6	1.5	69.0	1.5	-2.2
Light Autos (S)	71.3	1.7	70.4	2.1	69.3	1.6	69.2	1.3	-1.6
Large Truck, Multi-Axle (N)	77.4	1.9	78.9	1.6	76.0	N/A	N/A	N/A	-2.1
Large Truck, Multi-Axle (S)	79.2	1.7	78.6	2.1	79.0	N/A	80.0	N/A	0.6